Understanding Fiber Optics

Second Edition

JEFF HECHT

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UNDERSTANDING

DEDICATION

This book is dedicated to the many folks who've made fiber optics a fun place to be over the last two decades.

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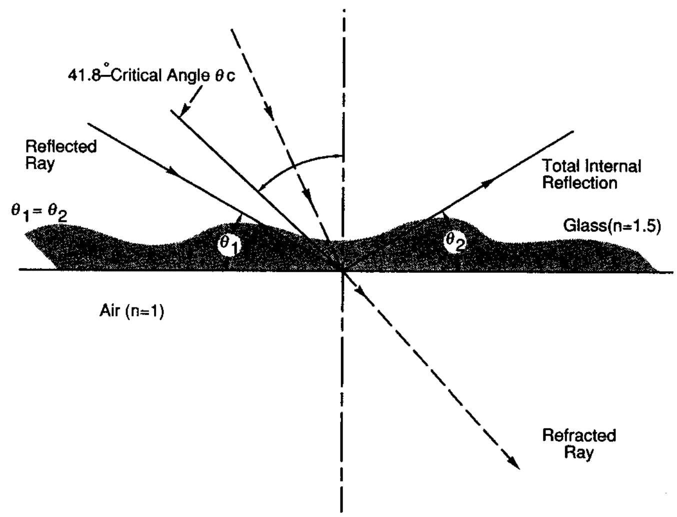
TRADEMARKS

FIGURE 2.5.
Refraction and total internal reflection.



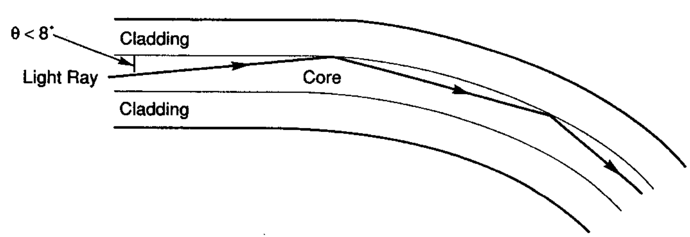
Light Guiding

Light is guided in the core of an optical fiber by total internal reflection at the boundary of the lower-index cladding.

The two key elements of an optical fiber—from an optical standpoint—are its core and cladding. The core is the inner part of the fiber, through which light is guided. The cladding surrounds it completely. The refractive index of the core is higher than that of the cladding, so light in the core that strikes the boundary with the cladding at a glancing angle is confined in the core by total internal reflection, as shown in Figure 2.6.

The difference in refractive index between core and cladding need not be large. In practice, it is only about 1%. This still allows light guiding in fibers. For $n_r/n_i = 0.99$, the critical angle θ_c is about 82°. Thus, light is confined in the core if it strikes the interface with the cladding at an angle of 8° or less to the surface. The upper limit can be considered the confinement angle in the fiber.

FIGURE 2.6.
Light guiding in an optical fiber.



Another way to look at light guiding in a fiber is to measure the fiber's acceptance angle—the angle over which light rays entering the fiber will be guided along its core, shown in Figure 2.7. (Because the acceptance angle is measured in air outside the fiber, it differs from the confinement angle in the glass.) The acceptance angle normally is measured as numerical aperture (NA), which for light entering a fiber from air is approximately

$$NA = (n_0^2 - n_1^2)^{1/2}$$

where n_0 is the refractive index of the core and n_1 is the index of the cladding. For a fiber with core index of 1.50 and cladding index of 1.485 (a 1% difference), NA = 0.21. An alternate but equivalent definition is the sine of the half-angle over which the fiber can accept light rays, 12° in this example (θ in Figure 2.7). Another alternate definition is $NA = n_0 \sin \theta_c$, where θ_c is the confinement angle in the fiber core (8° in this example).

The angle over which a fiber accepts light depends on the refractive indexes of the core and cladding glass.

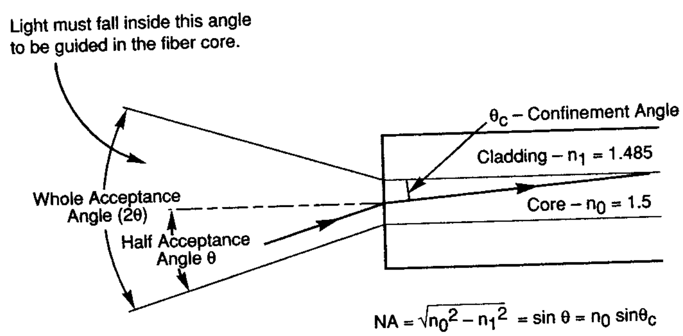


FIGURE 2.7. *Measuring the acceptance angle.*

Note that the half acceptance angle is larger than the largest glancing angle at which light rays must strike the cladding interface to be reflected, which I said earlier was 8°. What does this mean? Go back and look at Snell's law of refraction again. The difference is the factor n_0, which is the refractive index of the core glass, or 1.5. As you can see in Figure 2.7, refraction bends a light ray entering the fiber so that it is at a smaller angle to the fiber axis than it was in the air. The sine of the angle inside the glass equals that of the angle outside the glass, divided by the refractive index of the core (n_0).

Light Collection

Numerical aperture and acceptance angle measure a crucial concern in practical fiber-optic systems: getting light into the fiber. A century ago, British physicist Charles Vernon Boys made fine fibers of glass comparable in size to today's optical fibers, but as far as we know he didn't try to transmit light along their lengths. Even when the first optical fibers were developed in the 1950s, no one seemed to think that single fibers could collect much light. Instead, they grouped fibers into bundles that together could collect reasonable amounts of light. Only when lasers made highly directional beams available did researchers seriously begin to consider using single optical fibers.

Practical applications for single fibers require ways to get light into their small cores.